13th Annual Summer CubeSat Developer's Workshop
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Attitude Determination and Control System Design for STU-2A Cubesat and In-Orbit Results

Presented by **Shufan Wu**

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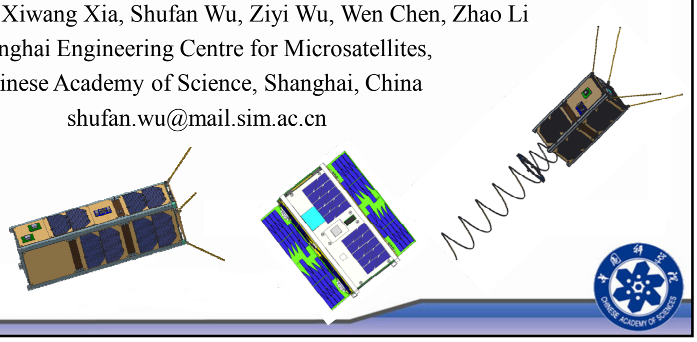


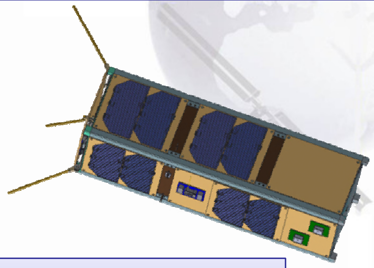
Outline

- **STU-2A Mission Overview**
- **ADCS Hardware**
- **ADCS Algorithm**
- **In-orbit Data Analysis and Experiment Results**
- **Lessons learned**

STU-2A Mission Overview

❑ Size&Mass

3U Cubesat with a mass of 2.9kg;
114 mm × 114 mm × 343.3 mm;
Launched on Sept. 25, 2015.



❑ Missions

taking pictures of polar with an onboard CMOS color camera;
Demonstration of Cubesats Networking based on Gamalink and CSP;
Demonstration of MEMS based cold-gas micropropulsion ;
In-orbit demonstration and verification of the GPS/Beidou receiver.

❑ Cubesats in China

STU-2 are the first batch of nano satellites in China that are made in accordance with the Cubesat standard.

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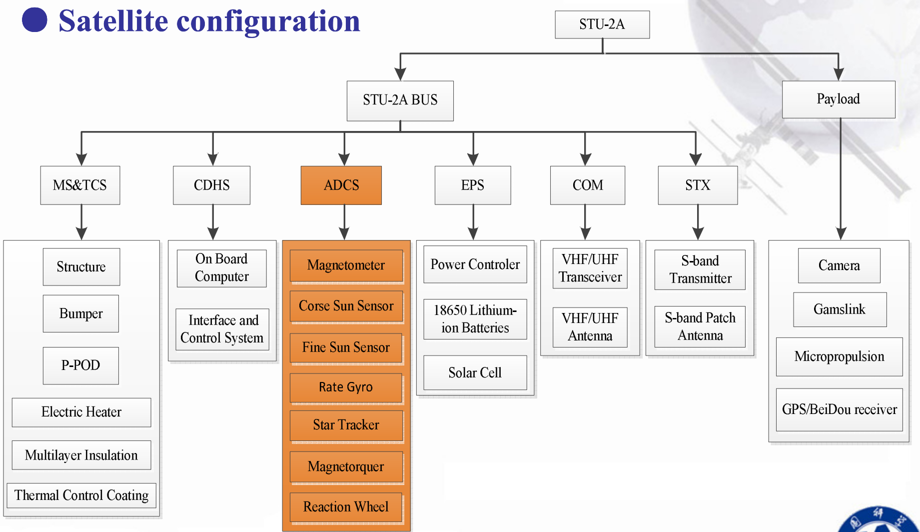
STU-2A Mission Overview

● Satellite configuration



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STU-2A Mission Overview

Requirements for ADCS

$$Vg \cdot t + S \cdot t \cdot h \leq 0.6 \cdot GSD$$

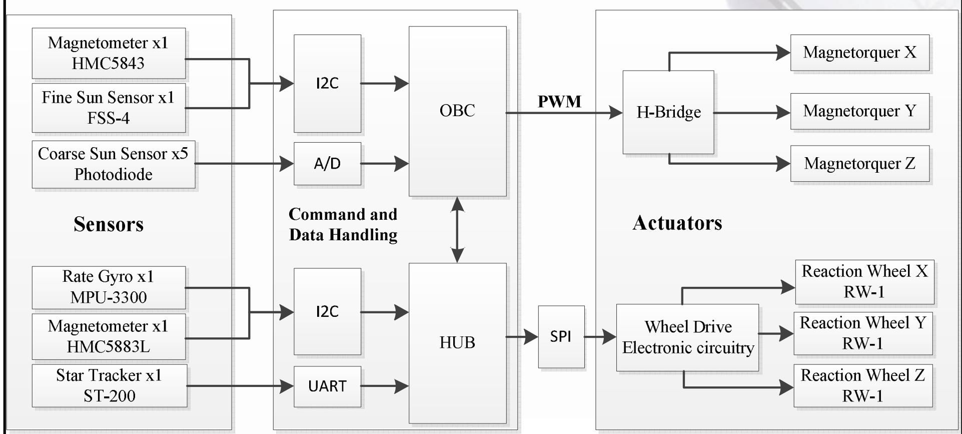
Pointing accuracy ≤2°
Attitude stability ≤0.28° /s.

Designed performance of ADCS

ADCS Performance	Value
Attitude Determination Precision	≤1° (3σ)
Pointing Accuracy	≤2° (3σ)
Attitude Stabilization Precision	≤0.1° /s

STU-2A Mission Overview

ADCS Subsystem Architecture



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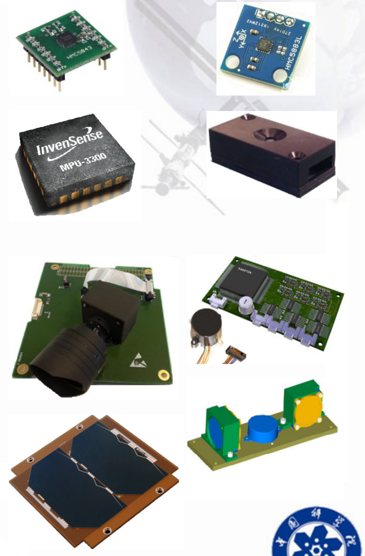
ADCS Hardware

Sensors and Actuators Type	
Attitude Determination Sensors	3-Axis Magnetometer HMC5843 ×1
	3-Axis Magnetometer HMC5883L ×1
	Coarse Sun Sensors SLCD-61N8 Photodiodes ×5
	MEMS 3-Axis gyro MPU-3300 ×1
	Fine Sun Sensor FSS-4 ×1
	Star Tracker ST-200 ×1
Attitude Control Actuators	Magnetic coils ×3
	Reaction wheels RW-1 ×3



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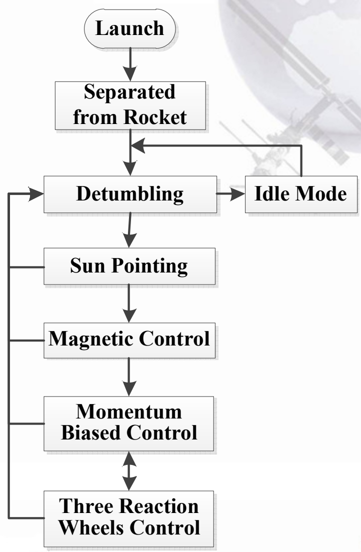
ADCS Algorithm

- **The basic algorithm is TRIAD, which determines the attitude by use of the knowledge from two non-parallel measuring vectors.**

- **A UKF algorithm is combined into the TRIAD algorithm to improve the attitude accuracy.**



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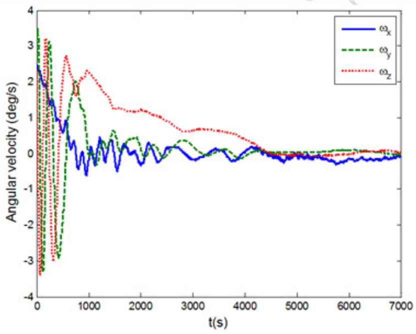
In-orbit Data Analysis and Results

●Detumbling Phase

94 minutes after launch, the first received signals showed that the satellite had completed rate damping (three axis angular velocity have been reduce within 0.3°/s) within one orbit period time and entered Sun Pointing Mode automatically.

The in-orbit result was in conformity with simulation.



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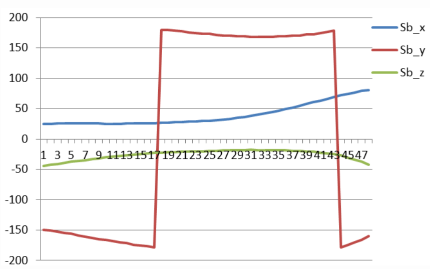
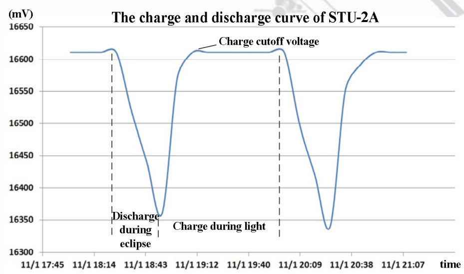
In-orbit Data Analysis and Results

●Sun Pointing / Sun Acquisition

Sun vector in body coordinate system

Charge-discharge curve





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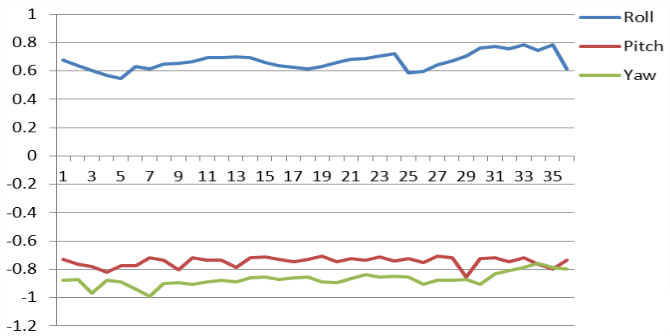
In-orbit Data Analysis and Results

●Nadir Pointing Mode

Three attitude angles were constrained within 1°.
The time period is from 08:20 to 08:26, 30th Sep, 2015.



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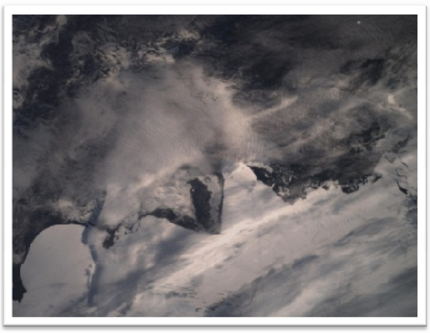
In-orbit Data Analysis and Results

●CMOS Camera Image



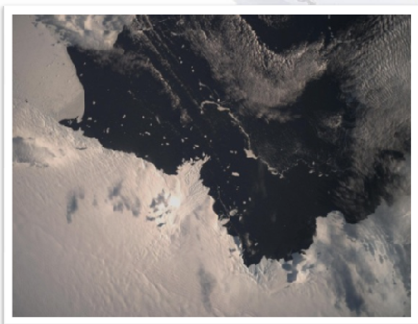


Image of polar glaciers captured on Feb 23 00:10:30 2016 UTC

Image of polar glaciers captured on Feb 23 23:41:34 2016 UTC

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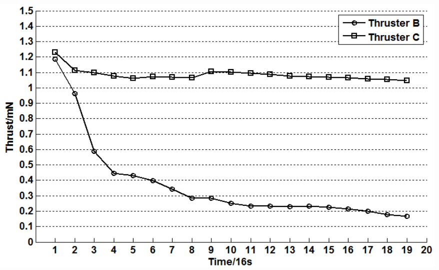
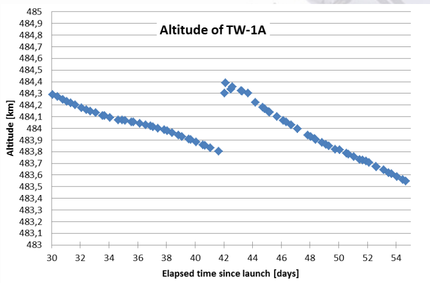
In-orbit Test Experiences – Thruster Firing

● **Micro-Propulsion In-Orbit Firing**

On Nov 5th 2015, 10:09(UTC), thruster B and C are commanded for 5 min firing @ 1mN, aiming to raise the orbit





● **Firing Results**

- ◆ Thruster B falls into problem rapidly
- ◆ Unbalanced thrust level leads high rate spinning
- ◆ Spinning rate upto ca 65 deg/s (measured by redundant MEMS gyro on Nano-Hub)
- ◆ The resulted orbit change becomes very limited – ca 0.6km

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In-orbit Test Experiences – Oscillation

● **Local Oscillation work-point at ca 65 deg/s**

- ➢ Initial tests try to reduce spin rate by counter-firing the thrusters
- ➢ Reduced 5 deg/s by firing in one pass, resumed back at ca 65 deg/s in next pass
- ➢ Reduced 10 deg/s by firing in one pass, back to 65 deg/s again in next pass

● **Local Oscillation work-point at ca 65 deg/s**

- ➢ Ts= 1 sec delay in the magnetic control loop (take the measurement before sending out the magnetic control, to separate disturbance)
- ➢ This delay in the control loop results in a steady oscillation work-point
- ➢ Simulation results revealed the oscillation work-point at ca 65 deg/s
- ➢ If remove the delay in simulation, the oscillation disappear

● **Condition back to 0 work-point**

- ➢ Simulation shows, the initial rate needs to be below 20 deg/s
- ➢ Then, magnetic control can reduce the rate down to zero

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In-orbit Test Experiences – Attitude Rescue

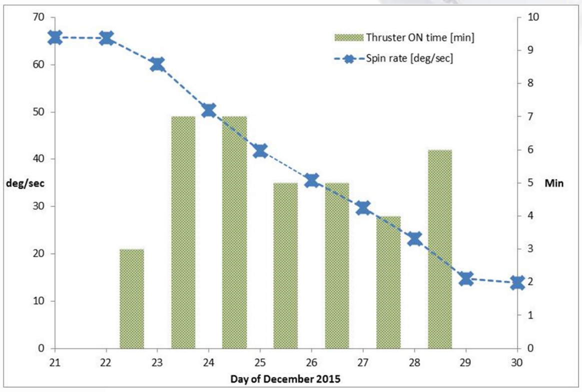
● Rescue Process

Successful ! Rescue around the 2015 Xmas week

- ➢ Switch off ADCS loop
- ➢ 7 days successive firing to reduce the rate
- ➢ Rate down to ca 14 deg/s
- ➢ Switch on the ADCS
- ➢ Magnetic control bring the spin rate down to zero

● Thanks to:

- ➢ CSP allows direct access to subsystem
- ➢ redundant MEMS gyro and magnetometer
- ➢ Open-loop control



Sequence of thrust firings to de-spin the STU-2A

Problems and Lessons Learned (1)

☐ Redundant back ups of key sensors & actuators

- ➢ Redundant MEMS gyro
- ➢ Redundant magnetometer
- ➢ Cold-gas thrusters - additional measure for attitude

☐Magnetic residuals

- ➢ leads to rotation in pitch axis – one rotation / orbit
- ➢ accurate attitude performance was not achieved in STU-2A
- ➢ the 18650 lithium-ion batteries could pose magnetic dipole

☐ In-orbit injection of control parameters & software patches

- ➢ very important to calibrate off-set or errors
- ➢ if so, residual dipole can be compensated
- ➢ if so, oscillation work-point @ 65deg/s can be removed

Problems and Lessons Learned (2)

- **Magnetic Rod vs Magnetic Coil**
  - Magnetic rod gives higher flux than coils built in the PCB
  - Thus to have more capacity to fight magnetic residuas
  - Rod is preferred if space allows
- **Magnetometer & Magnetorque layout**
  - Magnetometer shall be kept away from large current devices, e.g. PC-104 socket (TM pulses cause high current,…)
  - Magnetomer far away from magnetic coils or rods if possible
  - Mangetometer on a deployed boom is preferred if possible
- **Sensors testing coverage**
  - Fine sun sensor testing was not professional, accuracy degraded
  - Shall use Sun simulator at varying angles and temperatures to calibrate the accuracy

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